

Emergency and Abnormal Situations: In-Flight Smoke, Fires and Fumes

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Human Factors
research and technology

The Emergency and Abnormal Situations project is funded through the NASA Aviation Safety and Security Program.



The Challenge

Emergency and abnormal situations:

- are often time critical, complex, and/or ambiguous
- are high stress, high workload, and a great deal is at stake
- require exceptionally high levels of coordination inside and outside of the airplane

Emergency and abnormal procedures:

- are generally focused on aircraft systems rather than on the situation as a whole
- are practiced seldom (twice a year or less) and used rarely
- are often highly dependent on fragile cognitive processes
- **when needed, are crucial and must be performed correctly**



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Emergency and Abnormal Situations Project Industry Contacts and Consultants

Manufacturers: Boeing, Bombardier, Airbus Industries,
BAe Systems,

Regulatory and
Governmental Agencies: FAA, CAA (UK), JAA, ICAO,
Eurocontrol, NavCanada

Unions and
Trade Groups: ALPA, IFALPA, APA, SWAPA, ATA,
IATA, AFA, ADF

Accident Investigation
Bodies: NTSB, TSB of Canada, ISASI

Airlines: Airborne Express, Air Canada, Alaska,
Aloha, American, Atlantic Southeast,
Cathay Pacific, Continental, Delta, Fed
Ex, Frontier, Hawaiian, Horizon,
JetBlue, Southwest, United, UPS,
US Airways, TWA (prior to merger)



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Emergency and Abnormal Situations Project

Taxonomy of the Domain

15 Different Categories of Issues:

-  Broad, Over-arching Issues (3)
-  Issues Related to Checklists and Procedures (3)
-  Issues Related to Humans (5)
-  Issues Related to the Aircraft (2)
-  Issues Related to Training (1)
-  Selected Emergency Equipment and Evacuation Issues (1)



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AIR PACK FAULT

If pack not supplied:

If in single pack operation:

REMAINING PACK ON
PACK (Affected) OFF

If pack overheat:

If in single pack operation:

REMAINING PACK ON
PACK (Affected) OFF
PACK MODE SEL (Affected) MAN/COLD

When turb temp below limit:

PACK (Affected) ON
PACK (Affected) MAN CTL

If both packs inoperative:

MAX ALTITUDE 10,000 FT/MEA

WHEN Δ P BELOW 1 PSI:

RAM AIR ON

PROC: AIR PACK FAULT

If Pack Fault due to low bleed air supply, a bleed leak does not exist, and if WING ANTI-ICE not required:

BLEED VALVE (Affected sided) OFF
AIR X FEED MAN/IN LINE
PACK (Affected) ON

If above FL370:

ECON FLOW ON

END OF PROCEDURE

If Pack Fault due to low bleed air supply, a bleed leak does not exist, and if WING ANTI-ICE not required:

~~If Pack Fault due to low bleed air supply, a bleed leak does not exist, and if WING ANTI-ICE is not required:~~

If Pack Fault due to low bleed air supply, and if a bleed leak does not exist, and if WING ANTI-ICE is not required:



ABNORM 1-2

Sep 09/02

1. SINGLE ENGINE PROCEDURES

In-Flight Engine Shutdown

Accomplish an engine shutdown only when flight conditions permit:

- (1) Affected thrust lever CONFIRM AND IDLE
- (2) Affected thrust lever CONFIRM AND SHUT OFF
- (3) Affected HYDRAULIC pump ON
 - If left engine shut down HYDRAULIC 1 ON
 - If right engine shut down ... HYDRAULIC 2 ON
- (4) Affected FUEL, BOOST PUMP CONFIRM AND OFF
- (5) WING A / I CROSS BLEED SELECT NON-AFFECTED SIDE
- (6) LH or RH COWL ANTI-ICE AFFECTED SIDE OFF

QUICK REFERENCE HANDBOOK CSP C-022

POWER PLANT MALFUNCTIONS

Start



ABNORM 1-3

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Enroute terrain clearance is a consideration:

- Yes
- (7) Operating engine thrust lever SET TO CLIMB
- (8) Airspeed MAINTAIN ENROUTE CLIMB SPEED
- (9) Allow the airplane to climb or descend to the single engine level-off altitude.

- (10) APU (if available) (37,000 feet and below) START

NOTE
Do not attempt to relight an engine that is suspected to be damaged (engine fire, rotor burst, reverser deployed, etc...).

Engine damage is suspected/intentional shutdown:

- Yes
- (11) Land at the nearest suitable airport.
- (12) Single Engine Approach and Landing Procedure ACCOMPLISH (Refer to ABNORM 1-9)

- END -

- No
- (11) Engine Relight procedure .. ACCOMPLISH, as required
 - Starter-Assisted Cross Bleed Relight Procedure (Refer to ABNORM 1-3)
 - Starter-Assisted APU Bleed Relight Procedure (Refer to ABNORM 1-5)
 - Windmilling Relight (Refer to ABNORM 1-7)

Relight engine using starter-assisted start whenever possible.

----- END -----

- No
- (7) Proceed to step (10)

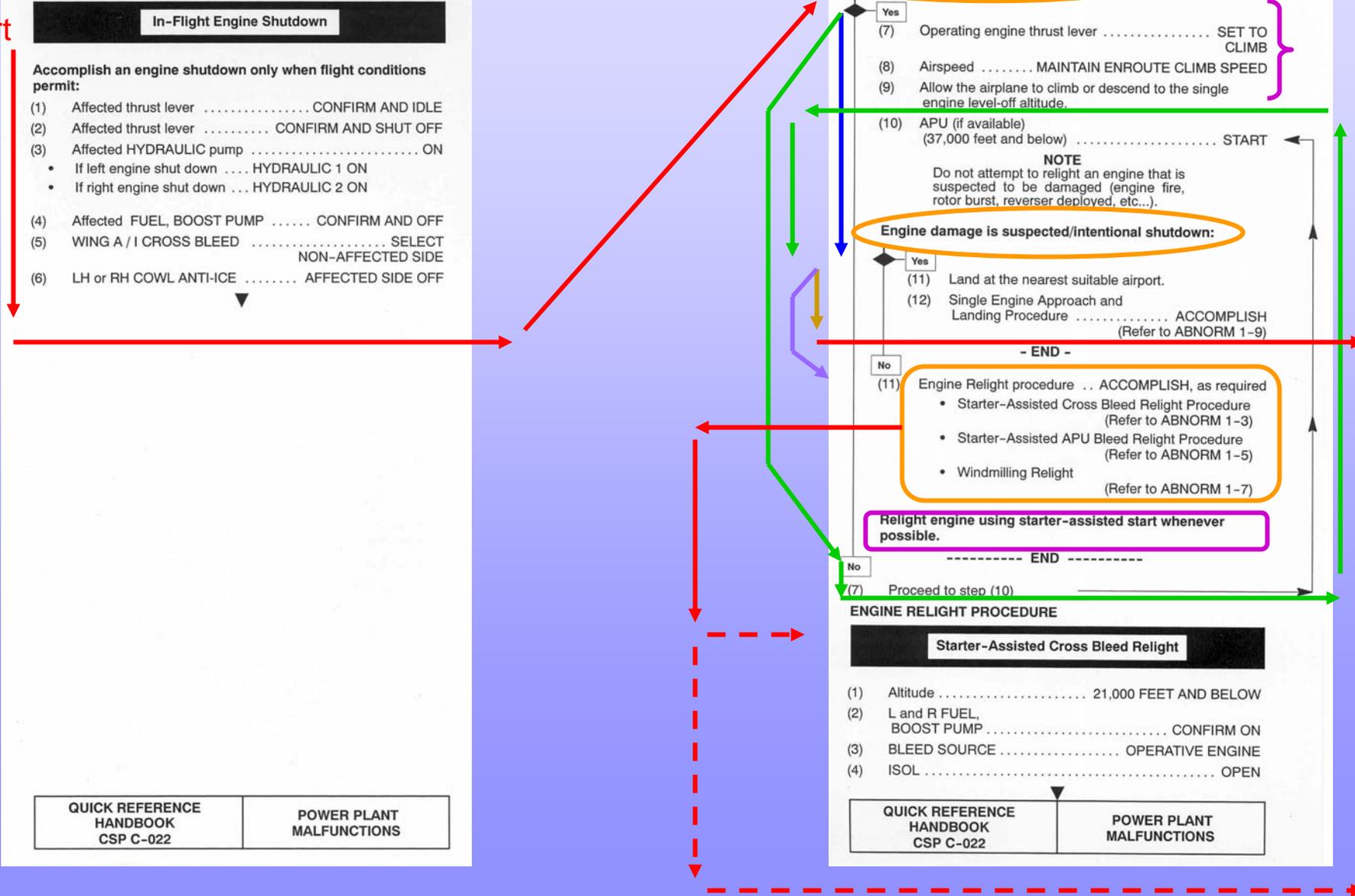
ENGINE RELIGHT PROCEDURE

Starter-Assisted Cross Bleed Relight

- (1) Altitude 21,000 FEET AND BELOW
- (2) L and R FUEL, BOOST PUMP CONFIRM ON
- (3) BLEED SOURCE OPERATIVE ENGINE
- (4) ISOL OPEN

QUICK REFERENCE HANDBOOK CSP C-022

POWER PLANT MALFUNCTIONS



Emergency and Abnormal Situations Project

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SAS 751 - MD-81 Dual Engine Failure – Gottröra, Sweden – December 27, 1991

On takeoff, ice was ingested into the engines which damaged the fan stages and caused the engines to surge – all power was lost 77 seconds later.



During the event engine power was increased automatically by the Automatic Thrust Restoration (ATR) feature, which increased the intensity of the surging and contributed to the failure of the engines.

Neither the crew nor the company knew that the ATR feature existed on the airplane.

Emergency and Abnormal Situations Project

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Airtran 356 - 717-200 – Flushing, New York – March 26, 2003
NTSB Preliminary Report



While on final approach the forward flight attendant noticed a burning smell and discovered that the handset to call the cockpit was not working.

After landing she pounded on the cockpit door and yelled to get the flight crew's attention.

The flight crew never heard the flight attendant pounding or yelling.



Overall Goal of the EAS Project

Develop guidance for procedure development and certification, training, crew coordination, and situation management based on knowledge of the operational environment, human performance limitations, and cognitive vulnerabilities in real-world situations.



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Challenges in Emergency and Abnormal Checklist Design

Smoke, Fire, and Fumes Checklists and Procedures



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Smoke, Fire, and Fumes Checklists and Procedures

A Few of the Many Design and Content Issues

- Location of checklists
- Determining / accessing the proper checklist
- Number of SFF checklists available and to choose between
- Length of checklist and amount of time needed to complete procedures
- General checklist design considerations
- Reduced visibility – font size, layout, color of text and background
- Paper vs. electronic checklists
- Various human factors considerations
- Ambiguity of cues / level of certainty about the situation
- Conflicting warnings / cues
- Smoke / fumes of an unknown origin
- Hidden fires / smoke or fire in inaccessible places



Smoke, Fire, and Fumes Checklists and Procedures

A Few of the Many Design and Content Issues, continued

- What memory Items, if any?
- How much time spent on source identification / troubleshooting?
- Initiating a descent / diversion and when
- What type of descent profile?
- Timing of source identification vs. smoke removal vs. descent initiation vs. fighting fire
- High false smoke alarm rate
- EROPS – nearest airport is far away
- Ditching while on fire
- Powering down electrical buses
- Circuit breaker resetting
- If / when to declare an emergency with ATC
- Communicating / coordinating with Cabin Crew



Smoke, Fire, and Fumes Checklists and Procedures

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Smoke, Fire, and Fumes Checklists and Procedures

Methods for Accessing the Correct Checklist (un-alerted / unannunciated events):

- Gateway Checklist
- Several Separate Checklists
- One Integrated Checklist



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Accessing the Correct Checklist: Gateway Checklist

FIRE & SMOKE	
1. Oxygen Mask & Smoke Goggles (As Required)	ON, 100%
2. Crew & Courier Communications	ESTABLISH
Check Mike switches set to MASK, place cockpit speaker ON, place MIC SEL switch to FLT INT, and establish crew communication.	
3. Cockpit Door & Smoke Screen	CLOSED
Close the cockpit door & smoke screen to exclude heavy concentrations of smoke. Leave door closed unless opening it is dictated by a greater emergency, and then at Captain's discretion.	
4. If Descent is required	PROCEED TO STEP 6
or	
5. If Descent Is NOT Required	PROCEED TO STEP 14
WARNING	
Should structural damage be suspected, limit airspeed. Gear and / or Speed Brakes may be used depending on type of damage.	
6. Autopilot	AS REQUIRED
7. Throttles	IDLE
8. Speed Brake	FULL
9. Airspeed	MACH .82 TO .85 (320 TO 350 KIAS)
NOTE	
If structural damage is known or suspected, use appropriate turbulence penetration speed.	
10. ATC	NOTIFY
11. Transponder (if no contact with ATC)	7700
12. Tank Pumps	ALL ON
13. Altimeter	SET
14. Type Of Smoke Or Fire	DETERMINE & PROCEED TO APPROPRIATE PROCEDURE, THIS CHAPTER
A. ELECTRICAL FIRE & SMOKE	: Can best be determined by smell or visible smoke from electrical components (e.g., circuit breaker, radio)
B. AIRCONDITIONING SMOKE	: Can best be recognized by smoke emanating from overhead air conditioning outlets.
C. CABIN CARGO SMOKE	: Can best be recognized by checking smoke detectors on the Second Officers panel, or by observing smoke or fire in the main deck cargo area.
(End of Procedure)	

Accessing the Correct Checklist: Several Separate Checklists

	EMER 2-1
	Sep 09/02

CONTENTS	PAGE
SMOKE OR FIRE	
• Flight Compartment Smoke Removal Procedure	
• Air-Conditioning Smoke	
• Electrical Smoke or Fire	
• Cabin Smoke or Fire	
• Galley Smoke or Fire	
• SMOKE AFT CARGO Msg	
• SMOKE FWD CARGO Msg	
• SMOKE FWD LAV or SMOKE AFT LAV Msg	

 767 Operations Manual	
Non-Normal Checklists	
Fire Protection	
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Accessing the Correct Checklist: One Integrated Checklist

SMOKE, CABIN/COCKPIT

- Oxygen masks and regulators On, 100%
 - Crew and flight attendant communications Establish
 - Cabin fans switch Off
 - Blower switch Override
 - Extract switch Override
 - Galley/galley and cabin switch Off
 - Descent Initiate
- WARNING:** Do not delay descent or diversion to find the smoke source.
- Cabin signs On

CONTINUED FROM QRC

If dense smoke at any time, accomplish reverse side.

REFERENCE ACTION:

If electrical, cabin, or galley equipment smoke/fire is suspected:

- Emergency exit light switch On
- If commercial switch installed:
- Commercial switch Off
- If commercial switch is not installed:
- Bus tie switch Off
 - Generator 2 switch Off
- If smoke persists or just before landing gear extension:
- Generator 2 switch On
 - Bus tie switch Auto

END

If air conditioning smoke is suspected:

- APU bleed switch Off
 - Blower switch Auto
 - Extract switch Auto
 - Pack 1 switch Off
- If smoke does not decrease:
- Pack 1 switch On
 - Pack 2 switch Off
 - Cargo heat aft isolation valve switch Off
- If smoke persists:
- Pack 2 switch On
 - Blower switch Override
 - Extract switch Override

END

If avionics smoke is suspected:

Accomplish AVIONICS SMOKE ECAM or Flight Manual procedure 14.20.39.

END

DENSE SMOKE

EMERGENCY DESCENT

- FCU altitude (safe altitude/10,000 feet) Set
- FCU expedite switch Push
- Target speed Confirm, .80M/340KIAS
- Thrust Confirm, idle
- Speed brakes Extend
- ATC Advise

SMOKE REMOVAL

- Pack flow selector High
- Landing elevation selector Safe altitude/10,000 feet

When at safe altitude/10,000 feet:

- Pack switches 1 + 2 Off
- Cabin pressure mode selector Manual
- Manual vertical speed control switch Full up

When differential pressure is less than 1 PSI:

- Ram air switch On

If cockpit smoke requires a cockpit window to be opened:

- Maximum speed 200 KIAS
- Headsets On
- Cockpit window Open

EMERGENCY ELECTRICAL CONFIGURATION (If Required)

- Emergency electrical generator 1 line switch Off
- Emergency electrical power switch Manual on

When emergency generator available:

- APU generator switch Off
- Generator 2 switch Off

Before landing gear extension:

- Generator 2 switch On
- Emergency electrical generator 1 line switch On

Integrated SFF Checklist Template

SMOKE / FIRE or FUMES

Condition: Smoke, fire or fumes is identified.

Protecting the crew and initial situation assessment.	
Step	Action
1	Anticipate Diversion
2	Oxygen Masks (If required)ON
3	Smoke Goggles. (If required)ON
4	Crew & Cabin CommunicationsEstablish
Accomplish SMOKE OR FUMES REMOVAL checklist any time smoke or fumes becomes the greatest threat. Page x.x.	
5	Source is obvious, accessible and extinguishable: <ul style="list-style-type: none"> • If Yes, Go to Step 6. • If No, Go to Step 8.
6	Isolate and extinguish the source. [If practical, remove power from affected equipment by switch or circuit breaker on the flight deck or in the cabin.]
7	Source confirmed to be extinguished and the smoke/fumes dissipating: <ul style="list-style-type: none"> • If Yes, Go to Step 19. • If No, Go to Step 8.

Initial steps.	
Step	Action
8	Manufacturers step A Accomplish
9	Manufacturers step B Accomplish
10	Manufacturers step C Accomplish
11	Initiate Diversion to the nearest suitable airport while continuing this checklist.
12	Smoke/fire/fumes conditions dissipating: <ul style="list-style-type: none"> • If Yes, Go to Step 17. • If No, Go to Step 13.

Smoke/fire/fumes persist after initial steps.

Do not delay landing to accomplish these steps.

Time and conditions permitting, accomplish these system related steps in order unless a specific system is suspected.

Step	Action
13	XXXX system actions Accomplish [Further actions to control/extinguish source.] <ul style="list-style-type: none"> • If conditions persist Go to next unaccomplished step. • If dissipating Go to Step 17.
14	YYYY system actions Accomplish [Further actions to control/extinguish source.] <ul style="list-style-type: none"> • If conditions persist Go to first unaccomplished step. • If dissipating Go to Step 17.
15	ZZZZ system actions Accomplish [Further actions to control/extinguish source.] <ul style="list-style-type: none"> • If conditions persist Go to first unaccomplished step. • If dissipating Go to Step 17.
16	Smoke/fire/fumes persist after all system related steps are accomplished: <ul style="list-style-type: none"> • Land Immediately • Go to Step 18.

Follow up items.

Step	Action
17	Land at the nearest suitable airport.
18	See Considerations below
19	Accomplish Smoke Removal checklist, if required. Page X.X
20	■ ■ (End of Checklist) ■ ■

Considerations

This area is to list considerations – such as; overweight landing, tailwind landing, etc. are OK in an emergency.

Smoke, Fire, and Fumes Checklists and Procedures

Checklist Design and Content Issues

Three In-flight Smoke, Fire, Fumes Accidents:

Swissair 111 September 2, 1998

FedEx 1406 September 5, 1996

Air Canada 797 June 2, 1983



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Smoke, Fire, and Fumes Checklists and Procedures

Swissair 111

- Location of checklists
- Determining / accessing the proper checklist
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- **Length of checklist and amount of time needed to complete procedures**
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- Reduced visibility – font size, layout, color of text and background
- Paper vs. electronic checklists
- Various human factors considerations
- **Ambiguity of cues / level of certainty about the situation**
- Conflicting warnings / cues
- **Smoke / fumes of an unknown origin**
- **Hidden fires / smoke or fire in inaccessible places**



Smoke, Fire, and Fumes Checklists and Procedures

Swissair 111

- What memory Items, if any?
- **How much time spent on source identification / troubleshooting?**
- **Initiating a descent / diversion and when**
- **What type of descent profile?**
- **Timing of source identification vs. smoke removal vs. descent initiation vs. fighting fire**
- High false smoke alarm rate
- EROPS – nearest airport is far away
- Ditching while on fire
- Powering down electrical buses
- Circuit breaker resetting
- If / when to declare an emergency with ATC
- Communicating / coordinating with Cabin Crew



Swissair 111 - In-flight Fire Nova Scotia, Canada September 2, 1998

SMOKE / FUMES OF UNKNOWN ORIGIN

CAB BUS P/B ----- OFF

Pause long enough for cabin crew to evaluate whether smoke or fumes decrease.

SMOKE / FUMES DECREASE

NO

Continue with cabin bus inoperative.

END

CAB BUS P/B ----- ON

SMOKE ELEC/AIR Selector ----- PUSH AND ROTATE

Rotate SMOKE ELEC/AIR Selector clockwise, pausing at each position long enough to evaluate whether smoke or fumes decrease. When a decrease is noted, leave selector in that position for rest of flight.

Continue with that generator channel and air system inoperative and observe associated consequences.

NOTE:

- When rotating the SMOKE ELEC/AIR Selector, the autothrottle will disengage and be unusable. The autopilot may disengage but then use another autopilot.
- Nuisance stick shaker may occur. (Stick shaker CBs on overhead panel: Captain E-1, F/O E-31)
- Following essential systems are inoperative or off in accordance with SMOKE ELEC/AIR Selector Pos.

SMOKE Selector Pos. 3/1 OFF:

only Captains VHF 1 and interphone available.

- DU 4, 5, 6; MCDU 2; FM3 2; IR3 2 (after 15 min).
- Radar 2; All Nav aids 2.
- BLEED AIR 1; PACK 1; ECON system; WING anti-ice.
- F/O pitot heat.
- Auto slat extension.
- Landing gear aural warning.
- Autobrakes.

FOR APPROACH:

- Set FLAP LIMIT Selector to OVRD 1.
- Go-around mode is not available.

SMOKE Selector Pos. 2/3 OFF:

- BLEED AIR 3; PACK 3; WING anti-ice.

- Aux pitot heat.
- Fuel dump low level.
- HORIZONTAL STABILIZER TRIM Switches on control column.
- Engine 2 reverser.

SMOKE Selector Pos. 1/2 OFF:

only VHF 2 and 3 available.

- DU 1, 2, 3; MCDU 1; FM3 1.
- IRS 1 and AUX IRS after 15 min, (AP no longer available).
- Radar 1; All Nav aids 1.
- BLEED AIR 2; PACK 2; WING and TAIL anti-ice.
- Captain pitot heat.
- GPWS, GPWS BELOW G/S lights.
- Auto ground spoilers.
- Engine reversers 1 and 3.

FOR APPROACH:

- Set FLAP LIMIT Selector to OVRD 2.
- On CAPT SISP push FD P/B to OFF.
- Go-around mode is not available.

If smoke/fumes are not eliminated, land at nearest suitable airport.

END

If smoke/fumes are not eliminated, land at nearest suitable airport

Smoke, Fire, and Fumes Checklists and Procedures

Emergency Descent and Diversion

In a study of 15 in-flight fires that occurred between January 1967 and September 1998, the TSB of Canada determined that the average amount of time between the detection of an on-board fire and when the aircraft ditched, conducted a forced landing, or crashed was 17 minutes.

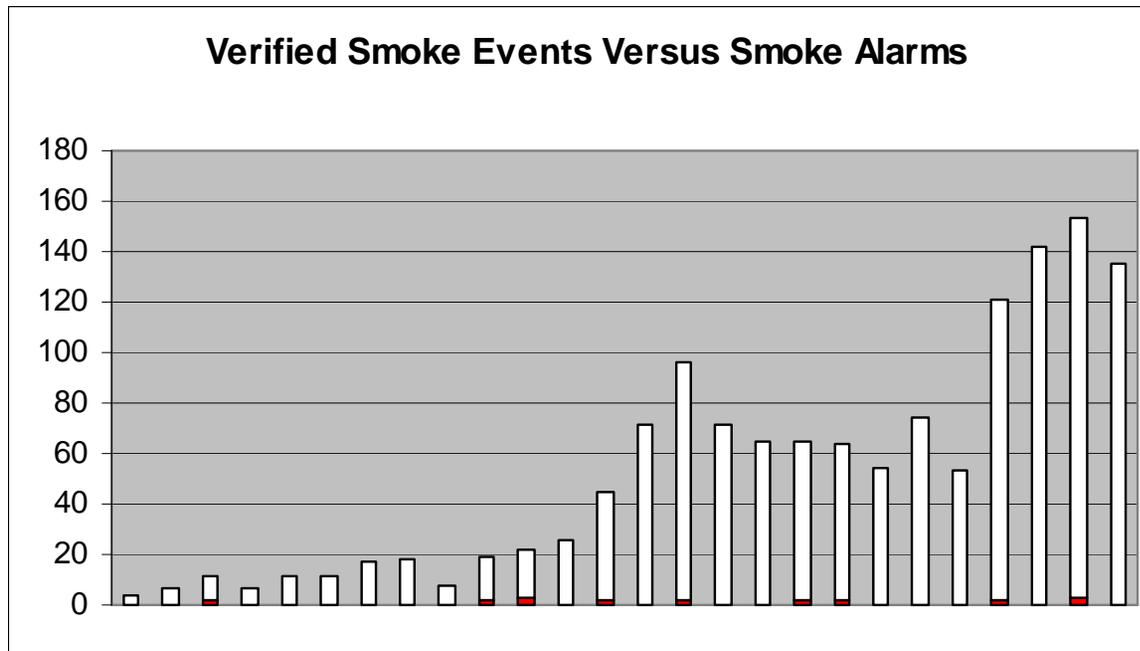


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Smoke, Fire, and Fumes Checklists and Procedures

False Cargo Smoke Alarms, 1974 -1999



D. Blake, 2000

Cost of Diversions: fuel, passenger ill-will, operational considerations, aircraft and crew scheduling, possible evacuation injuries, etc.



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Smoke, Fire, and Fumes Checklists and Procedures

FedEx 1406

- Location of checklists
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- **General checklist design considerations**
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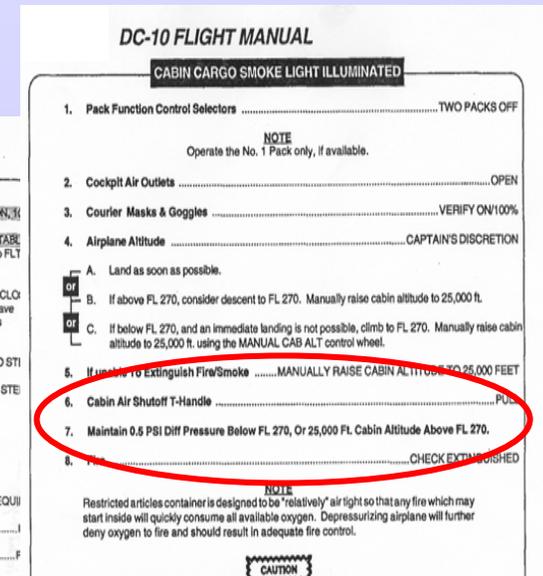
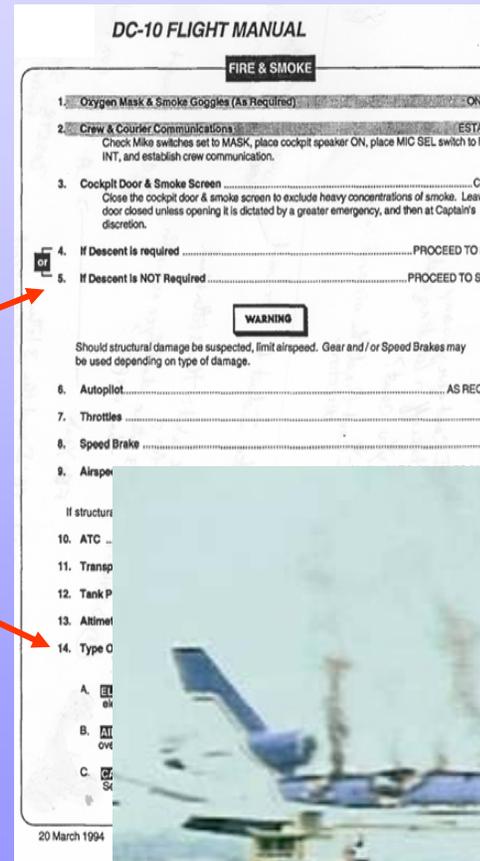




FedEx 1406, DC-10 In-flight Fire – Newburgh, New York September 5, 1996

In a rapidly deteriorating situation under high stress and workload, some checklist steps were not completed, which resulted in the aircraft being partially depressurized after making an emergency landing.

The crew and two passengers barely escaped the burning aircraft.



FedEx 1406, DC-10 September 5, 1996

Events:

- FE was confused by step 5
- did not complete step 6
- did not appear to complete step 7

CABIN CARGO SMOKE LIGHT ILLUMINATED

1. Pack Function Control Selectors TWO PACKS OFF

NOTE
Operate the No. 1 Pack only, if available.
2. Cockpit Air Outlets OPEN
3. Courier Masks & Goggles VERIFY ON/100%
4. Airplane Altitude CAPTAIN'S DISCRETION
 - A. Land as soon as possible.
 - or** B. If above FL 270, consider descent to FL 270. Manually raise cabin altitude to 25,000 ft.
 - or** C. If below FL 270, and an immediate landing is not possible, climb to FL 270. Manually raise cabin altitude to 25,000 ft. using the MANUAL CAB ALT control wheel.
5. If unable To Extinguish Fire/Smoke MANUALLY RAISE CABIN ALTITUDE TO 25,000 FEET
6. Cabin Air Shutoff T-Handle PULL
7. Maintain 0.5 PSI Diff Pressure Below FL 270, Or 25,000 Ft. Cabin Altitude Above FL 270.
8. Fire CHECK EXTINGUISHED

NOTE
Restricted articles container is designed to be "relatively" air tight so that any fire which may start inside will quickly consume all available oxygen. Depressurizing airplane will further deny oxygen to fire and should result in adequate fire control.

CAUTION

No crewmember should leave the cockpit to fight a fire except when it is determined that the fire is accessible and then only when measures already taken have not been effective. In addition, do not open restricted articles container during flight when a fire within is known or suspected.
9. If It Is Necessary To Leave The Cockpit To Fight A Fire:
 - A. Protective Breathing Equipment DON/ACTIVATE

NOTE
The PBE is located in a container in the coat closet and should be worn when fighting an actual fire. The walk-around O₂ bottle is also available in the cockpit.
 - B. Fire extinguisher OBTAIN
 - C. Fire or smoke source EXTINGUISH
10. Land At Nearest Suitable Airport.

(End of Procedure)

FedEx 1406, DC-10
September 5, 1996

Items Pertaining to Adjusting Cabin Altitude or Flight Level

4. Airplane AltitudeCAPTAIN'S DISCRETION

A. Land as soon as possible.

or

B. If above FL 270, consider descent to FL 270. Manually raise cabin altitude to 25,000 ft.

or

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Smoke, Fire, and Fumes Checklists and Procedures

Air Canada 797

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Smoke, Fire, and Fumes Checklists and Procedures

Air Canada 797

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- Ditching while on fire
- Powering down electrical buses
- Circuit breaker resetting
- If / when to declare an emergency with ATC
- **Communicating / coordinating with Cabin Crew**



Air Canada 797 - DC-9 In-flight Fire, Covington, Kentucky June 2, 1983

Initial actions taken by cabin crew to assess and deal with fire were inadequate

Captain was told the smoke was lessening – 5 ½ minute delay in starting emergency descent

After poor handoff, ATC identified the wrong radar target as the emergency flight



First officer turned the airconditioning and pressurization packs off

Toxic fumes and gases built up, a flash fire occurred soon after landing and 23 passengers died.

NASA Technical Memorandum

Smoke, Fire, and Fumes Checklists: Design and Content Considerations

(Work Currently in Progress)



Human Factors
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